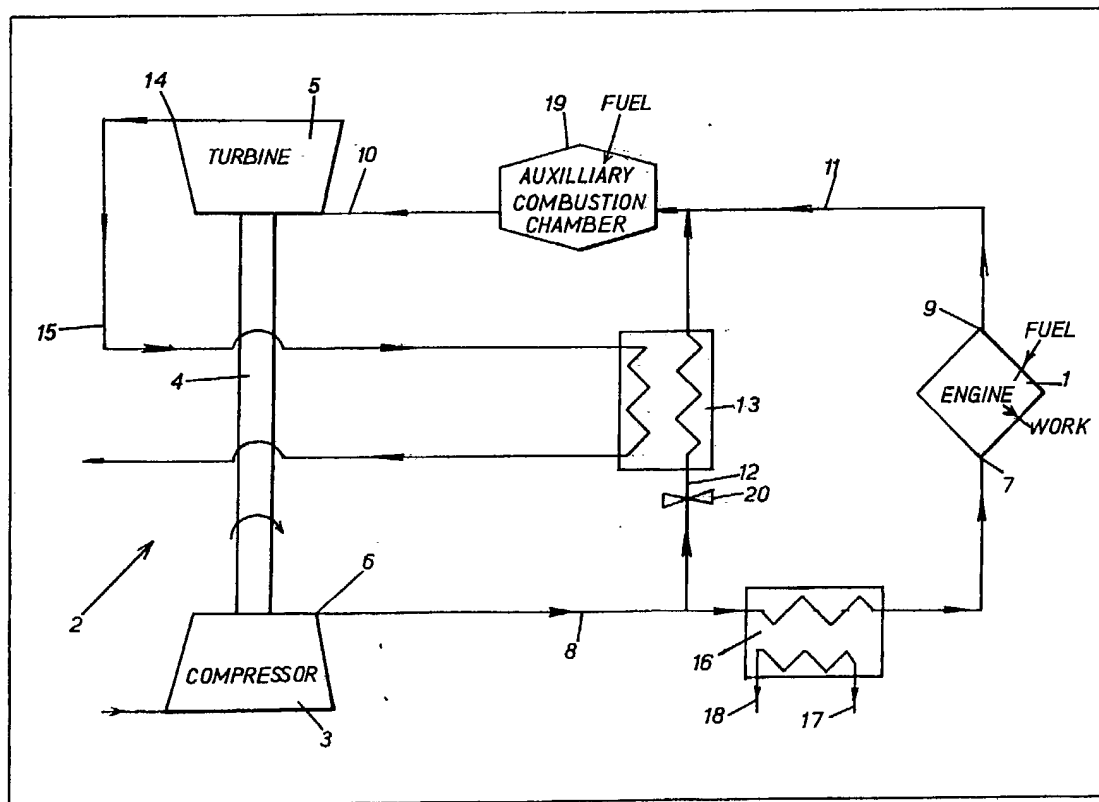


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- (71) Applicants  
The Secretary of State for  
Defence, Whitehall,  
London SW1A 2HB.
- (72) Inventor  
Bryan Lawton
- (74) Agents  
D. B. WILDMAN

## (54) Turbo-Charged compression ignition engines

(57) The engine 1 and the turbo-compressor set 3, 4, 5, wherein the turbine 5 is powered by engine exhaust gas, the turbine is mechanically coupled to drive the compressor 3, and the compressor provides the air supply to the engine are provided with a by-pass 12 in parallel with the engine 1 connecting the compressor outlet 6 with the turbine inlet 10, the by-pass including a heat exchanger 13 through which turbine exhaust gas can give up heat to air in the by-pass. A cooler 16 is connected between the compressor outlet 6 and the engine inlet 7 and an auxiliary combustion chamber 19 between the engine outlet and turbine inlet.



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## SPECIFICATION

**Turbo-Charged compression ignition engines**

5 This invention relates to compression ignition engines, and in particular to power units comprising a compression ignition engine supercharged by means of a turbo-compressor set. The engine can be, for example, a reciprocating diesel engine or a  
10 Wankel diesel engine.

In known arrangements, the turbine of the turbo-compressor set is driven by the exhaust gases of the engine. The compressor, which is driven by the turbine, then supplies air at increased pressure to the  
15 engine intake. Such an arrangement has the advantage that compression is effected in two stages, firstly in the compressor and finally in the engine itself. A diesel engine must normally operate on a compression ratio of at least about 12:1 in order to  
20 be self-sustaining. In a naturally aspirated engine this compression must be achieved entirely within the engine itself, and the advantages of supercharging in terms of size, weight, and cost of the engine are well recognised. These advantages are clearly  
25 such as to render a supercharged diesel engine attractive for automotive applications. However, its use in this field has been held back because the need to match characteristics of the turbo-compressor unit with those of the engine has resulted in a severe  
30 limitation being imposed on the useful speed range of the engine. This means that for automotive applications, the engine must be provided with a gearbox having a large number of closely spaced gear ratios. This causes an increase in cost which is generally  
35 sufficient to outweigh the advantage of supercharging, and also renders the vehicle less convenient to drive. Thus, while the turbo-charged diesel engine has found favour in constant-speed applications such as power generation, in general it has not  
40 enjoyed great success in the automotive field.

The limitation on useful speed range, which is the reason for this lack of success, arises as follows. In a simple power unit in which a diesel engine is supercharged by a turbo-compressor set powered by  
45 engine exhaust gas, the whole flow of air through the compressor must also pass through the engine. The compressor mass flow rate is thus governed by engine speed. If the engine speed falls below a certain value, the mass flow rate through the compressor will fall to a correspondingly low value below  
50 which the compressor will not perform satisfactorily, ie the compressor will be forced to operate below the surge line of its operating characteristic. In practice the problem of compressor surge in such a simple  
55 system places severe limitations on the practical range of engine speeds.

In British Patent Specification No 1 429 493 there is disclosed an arrangement in which this simple power unit is modified by the provision of a by-pass  
60 pipe through which air can pass directly from the compressor outlet to the turbine inlet without passing through the engine. In the system disclosed, a control valve is provided in the by-pass pipe, by which a constant pressure drop is arranged to occur  
65 through the by-pass pipe for a range of air flow rates.

Another arrangement in which a by-pass pipe is provided is disclosed, for example, in British Patent Specification No 1 291 030. In both of these arrangements, an auxiliary combustion chamber is  
70 provided upstream of the turbine, for use in starting the turbo-compressor unit. Whilst the prior documents mentioned do not specifically recognise the fact, it is appreciated by the present applicant that the provision of a by-pass pipe can lead to a solution to the problem of compressor surge at low engine  
75 speeds.

However, the use of a by-pass pipe introduces a further difficulty in the operation of the turbo-compressor set at low engine speeds, which arises  
80 as follows. When the engine is running at slow speed, in order to avoid the problem of compressor surge, a large proportion of the compressor output flows through the by-pass pipe, and conversely a small proportion flows through the engine. The turbine thus receives a mixture of by-pass air and  
85 engine exhaust gas, so that at low engine speeds the turbine air inlet temperature falls. As a consequence the turbine speed falls, and the compressor boost pressure and hence engine performance falls also.

90 According to the present invention, a power unit comprises a compression ignition engine and a turbo-compressor set, the compressor outlet being connected to the engine inlet, the engine outlet being connected to the turbine inlet, wherein a by-pass conduit in parallel with the engine connects the  
95 compressor outlet with the turbine inlet, and a heat exchanger is located in the by-pass conduit, exhaust gas from the turbine being constrained to flow through the heat exchanger.

100 Heat contained in the turbine exhaust gas can thus be utilised to increase the temperature of the gas flowing in the by-pass conduit prior to its being mixed with the engine exhaust gas and entering the turbine. In this way, the range of useful engine  
105 operating speeds can be extended, and fuel consumption at low speeds can be much improved.

In order that the invention may be better understood, an embodiment thereof will now be described by way of example only with reference to the  
110 accompanying drawing, which is a diagrammatic illustration of a power unit in accordance with the invention. In the drawing, there is shown represented an engine 1 which can be any compression ignition engine such as a reciprocating diesel engine or a Wankel diesel engine. The engine is super-  
115 charged by means of a turbo-compressor set 2 comprising a compressor 3 driven through a shaft 4 by a turbine 5. The compressor outlet 6 is connected to the engine inlet 7 by means of a conduit 8 and the engine outlet 9 is connected to the turbine inlet 10 by  
120 means of a conduit 11. A by-pass conduit 12 in parallel with the engine 1 connects the compressor outlet 6 with the turbine inlet 10 via sections of the conduits 8 and 11. A heat exchanger 13 is provided in the  
125 by-pass conduit, and turbine exhaust gas is constrained to flow from the turbine outlet 14 via conduit 15 to the heat exchanger 13. An air cooler 16 is optionally provided in the conduit 8 upstream of the junction between conduits 8 and 12, and coolant can  
130 be supplied to the air cooler via coolant inlet 17 and

coolant outlet 18. An auxiliary combustion chamber 19 is provided in the conduit 11 downstream of the junction between conduits 8 and 11, and a by-pass air flow control valve 20 is provided in the by-pass conduit 8.

The power unit is started by first starting the turbo-compressor set as follows. With the engine 1 at rest the valve 20 is fully opened, the turbo-compressor set 2 is rotated by external means, eg an electric starter motor, and a fuel supply is made available to the auxiliary combustion chamber 19 and ignited. This generates high temperature gas to drive the turbine 5, which drives the compressor 3 through the shaft 4. Further gas is made available from the compressor to the turbine via conduits 8, 12 and 11, and the turbo-compressor set rapidly reaches an operating speed, when the electric starter motor is switched off.

The valve 20 is then closed somewhat, to generate a pressure drop between conduits 8 and 11, ie between the engine inlet 7 and engine outlet 9, and the engine is turned over by external means, eg an electric starter motor. The compressor might typically provide a boost pressure of about 3.5 bar, so that if the engine itself provides a compression ratio of say 5:1, the overall compression ratio will be about 17.5:1 and compression ignition will readily occur. The engine/turbine-compressor set will rapidly become self sustaining, ie the electric starter motors need only be briefly operated, and the fuel supply to the auxiliary combustion chamber can be discontinued.

The air cooler 16 acts to cool and thus increase the density of the hot gas provided by the compressor, so increasing the air mass flow rate through the engine for a particular engine speed.

When the engine speed is high, the engine will take most of the air provided by the compressor, and there will be little air flow through the by-pass conduit 12. Consequently the gas reaching the turbine inlet 10 is mainly hot engine exhaust gas — typically at a temperature of around 600°C. Thus although the auxiliary combustion chamber is no longer operating, the turbine receives gas at a high enough temperature to sustain adequate performance, ie to drive the compressor so as to maintain a sufficient boost pressure.

However, if the engine speed falls, the engine no longer requires the full output of the compressor, and an increasing proportion of the compressor output flows through the by-pass conduit. This by-pass air is relatively cool, and dilutes the hot engine exhaust gas in the conduit 11, so that the turbine inlet temperature falls. In the absence of the heat exchanger 13 this would result in a significant fall in compressor speed and boost pressure, so that with a constant fuel injection rate the engine air/fuel ratio would fall until the smoke limit was reached. The speed range of the engine is effectively limited at the lower end by the smoke limit, and hence any method by which the smoke limit can be made to occur at a lower engine speed will widen the engine's effective speed range.

This is effectively achieved by the inclusion of heat exchanger 13 in the by-pass conduit 12. By this

means, the relatively cool by-pass air is heated prior to mixing with the hot engine exhaust gases, and a useful increase in turbine entry temperature can be obtained when the engine is operating at low speeds. Computer studies on one particular model layout including a diesel Wankel engine predict that the use of a heat exchanger in this way can increase turbine entry temperature by about 30°K at the lower end of engine speed range, and at the same time increase boost pressure and trapped air/fuel ratio by about 20%. Whilst at first sight the figure of 30°K may appear small, the same computer studies further predict that the use of the heat exchanger can increase the useful speed range of the engine from about 40% of maximum speed to about 51% of maximum speed, ie an increase of 28% on the useful speed range of the engine, and that fuel consumption at such speeds can be reduced by about 15%.

#### CLAIMS

1. A power unit comprising a compression ignition engine and a turbo-compressor set, the compressor outlet being connected to the engine inlet, the engine outlet being connected to the turbine inlet, wherein a by-pass conduit in parallel with the engine connects the compressor outlet with the turbine inlet, and a heat exchanger is located in the by-pass conduit, exhaust gas from the turbine being constrained to flow through the heat exchanger.

2. A power unit according to claim 1 wherein there is provided in the by-pass conduit a by-pass air flow control valve.

3. A power unit according to claim 1 or claim 2 wherein there is provided an air cooler in the connection between the compressor outlet and the engine inlet.

4. A power unit according to claim 2 comprising external means for rotating the turbo-compressor set, an auxiliary combustion chamber to which fuel can be supplied located in the connection between the engine outlet and the turbine inlet, and external means for rotating the engine.

5. A power unit according to any one preceding claim wherein the engine is a Wankel diesel engine.

6. A power unit according to any one preceding claim wherein the engine is a reciprocating diesel engine.

7. A power unit substantially as hereinbefore described with reference to the accompanying drawing.

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ABSTRACT:

CHG DATE=19990617 STATUS=O> The engine 1 and the turbo-compressor set 3, 4, 5, wherein the turbine 5 is powered by engine exhaust gas, the turbine is mechanically coupled to drive the compressor 3, and the compressor provides the air supply to the engine are provided with a by-pass 12 in parallel with the engine 1 connecting the compressor outlet 6 with the turbine inlet 10, the by-pass including a heat exchanger 13 through which turbine exhaust gas can give up heat to air in the by-pass. A cooler 16 is connected between the compressor outlet 6 and the engine inlet 7 and an auxiliary combustion chamber 19 between the engine outlet and turbine inlet. <IMAGE>